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DOE/NASA TECHNICAL
MEMORANDUM

DOE/NASA TM-73169

DESIGN AND OPERATION OF A SOLAR HEATING AND COOLING
SYSTEM FOR A RESIDENTIAL SIZE BUILDING

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For the U. S. Department of Energy

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16. ABSTRACT <p>The first year of operation of the Marshall Space Flight Center's Solar House is discussed. Selected design information, together with a brief system description, is included. The house is equipped with an integrated solar heating and cooling system which uses fully automated state-of-the art equipment. Overall performance for the first year is summarized. In addition, information pertaining to modifications made to improve performance is provided, and problems encountered during operation are discussed.</p> <p>Evaluation of data from the first year of operation indicates that the MSFC solar house heating and cooling system is capable of supplying nearly 100 percent of the thermal energy required for heating and approximately 50 percent of the thermal energy required to operate the absorption cycle air conditioner. The lower percentage of energy provided for the cooling mode as compared to the heating mode is due to the significantly higher temperature needed to operate the air conditioner, requiring the solar collector to operate at low efficiencies due to the higher inlet temperatures. Operation of the facility in the cooling mode has shown the need for basic subsystem improvements such as decreasing the operating temperature of the air conditioner and/or improving collector performance.</p>			
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1. INTRODUCTION

The design of a residential solar driven heating and cooling system (solar house) was initiated at Marshall Space Flight Center (MSFC) in August of 1973. System testing started in May 1974. The solar house has been in continuous operation since May 1974, with the exception of short times for modifications and special subsystem tests. Due to schedule and resource constraints, the system was not optimized for cost and energy usage. The major objectives of the solar house program are as follows:

- a. Demonstrate the technical feasibility of constructing a residential solar driven heating and cooling system using state-of-the-art construction methods, equipment, and materials.
- b. Provide a test bed for the evaluation of unique and/or innovative materials, coatings, and hardware in an operational system.
- c. Through system testing, confirm the major system design parameters such as minimum air conditioner operating temperature and energy requirements, efficiency of solar energy collection, system control, and overall system energy losses.
- d. Define and implement modifications for system and/or subsystem improvements and verify improvements by test.
- e. Verify system and subsystem math models for use in future system design analyses.

A comprehensive description of the house together with detailed data for the first summer of operation has been reported previously [1,2]; therefore, the system description and cooling mode operation given herein are abbreviated.

Selected design rationale used in initial design is included with the system description to provide better insight into the design philosophy.

During the first year of operation of the solar house, several modifications have been made to the original design. Some of the changes have been made to improve performance and others have been made to correct problems which were encountered during testing. A summary of system modifications is provided, and some of the problems which have been encountered are discussed.

A summary of system performance for the year is provided. In addition, a brief discussion of the effects of local environmental conditions on absorption air conditioner performance is presented.

It should be noted that the use of any particular component or material does not constitute endorsement. A number of studies being pursued at MSFC are expected to yield subsystems/components superior to those in the solar house.

2. DESCRIPTION AND DESIGN RATIONALE

General. The MSFC solar house incorporates the three basic ingredients which combine to form most solar heating and cooling systems: a solar collector, an energy storage subsystem, and a heating and/or cooling subsystem. These are joined together by a suitable plumbing and control/logic network to allow fully automated temperature control of the 141.4 m^2 (1520 ft^2) living area (Fig. 1). The living area was formed by joining three surplus trailers with wall partitions added to form seven rooms (Fig. 2).

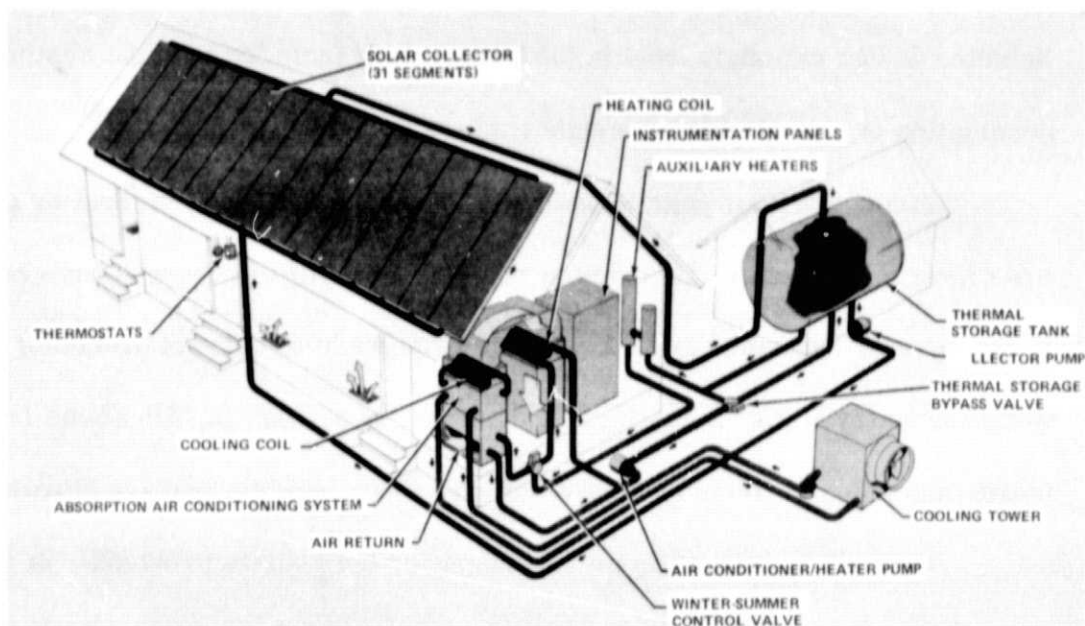


Fig. 1. MSFC solar system schematic.

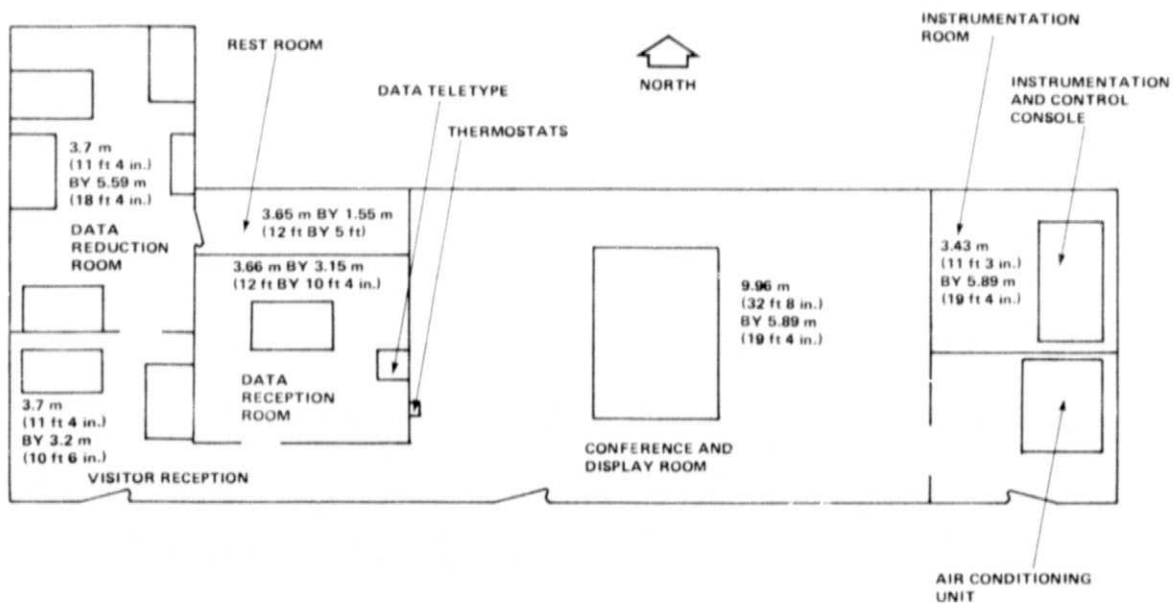


Fig. 2. Solar house floor plan.

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The collector subsystem consists of 120.9 m^2 (1300 ft^2) of collector, tilted 45 degrees, and composed of thirty-one 0.6 m by 6.4 m (2 ft by 21 ft) segments mounted side by side on the south face of the roof. Fourteen steel columns independently support the roof and collector subsystem, (Fig. 3). Each segment has a single plastic Tedlar cover supported by wire mesh. These covers are stretched over an aluminum tray which houses the collector panels and the backside insulation. The collector segments are formed by welding seven 0.6 m by 0.9 m (2 ft by 3 ft), 1100 series aluminum "Rollbond" panels in series (Fig. 4). The collector panels were limited in size to allow coating in existing MSFC vats.

Tedlar was considered to be attractive as a cover material because of its light weight and potential low cost. However, very little test data were available for this material under actual operational environments. Aluminum collector panels were used rather than copper because of the higher cost of copper. When considering steel panels, it was discovered that no mass production panel manufacturing capability existed using this material.

Collector panels were electroplated with a special black nickel/bright nickel selective coating developed at MSFC. This coating, although known to be susceptible to degradation due to moisture, was used because of its superior optical properties as applied (i.e. solar absorptance $\alpha = 0.92$, infrared emittance $\epsilon = 0.06$). Selective coatings of this type are needed to increase significant energy collection at the elevated temperatures required to operate

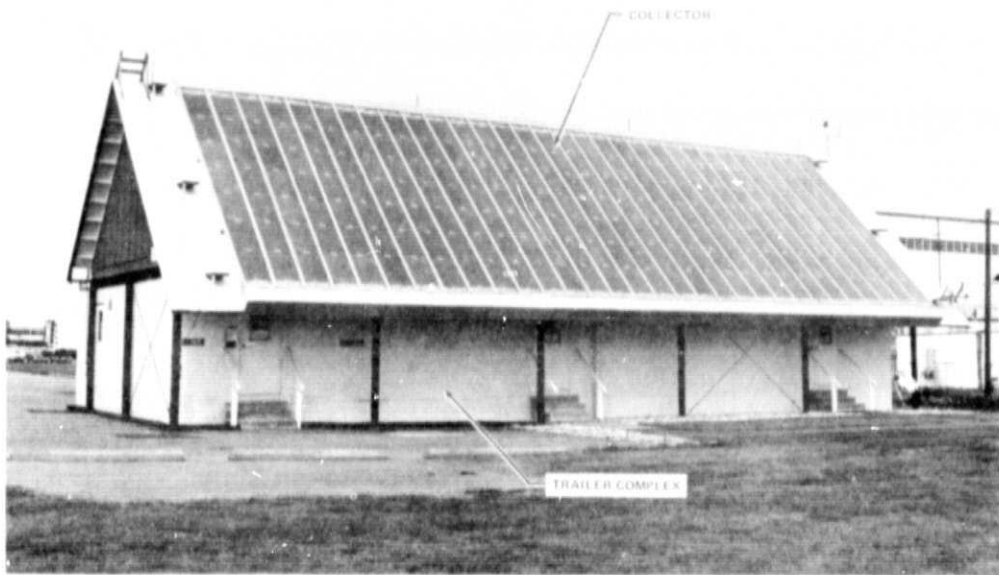


Fig. 3. Solar house.

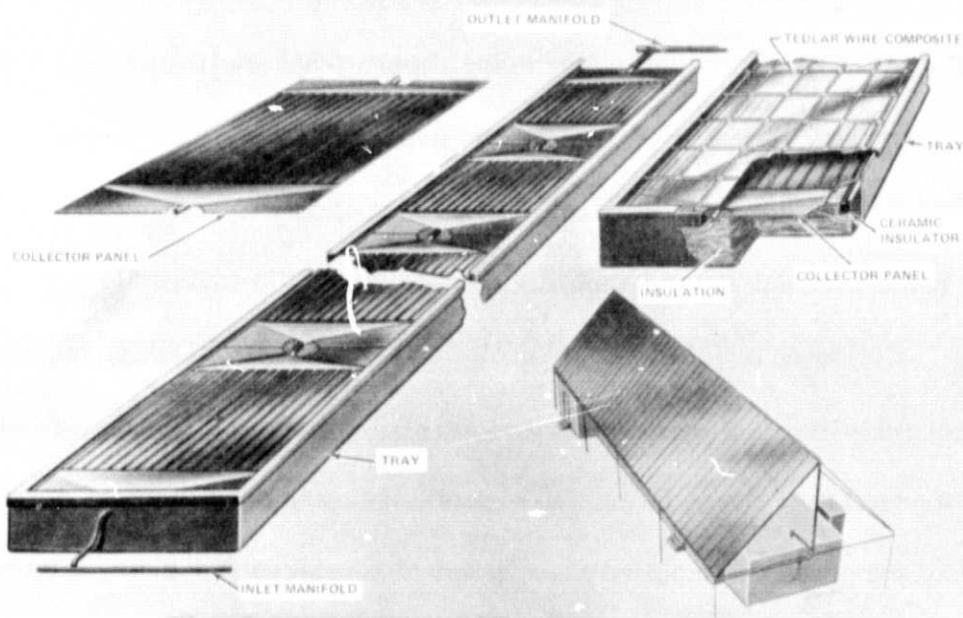


Fig. 4. Solar collector assembly.

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the absorption air conditioner, i. e. approximately 93°C (200°F). A closed loop air dryer was originally used to remove moisture in the collectors to protect the coating from high ambient humidities. A passive dehumidification system was installed later to replace the active system. This dehumidification technique will be discussed in a subsequent section. Standard 0.15 m (6 in.) thick household fiber glass was used for backside insulation.

The transport medium used is deionized water which is also common to the air conditioner/heater fluid loop and the energy storage tank. This water is inhibited with approximately 750 ppm by weight of sodium chromate to prevent corrosion. To avoid using expensive freezing depressants (e.g. ethylene glycol/water), automatic collector draining is used. Depressants were not used because they have the disadvantage of decreasing the system's thermal efficiency especially when used in conjunction with interface heat exchangers which are commonly used to decrease total depressant volume requirements. The energy storage tank was provided with sufficient gas volume to allow the dormant liquid level to be below the inlet collector manifold.

Energy Storage Tank. The energy storage tank (Fig. 5) is a surplus 21.4 m³ (4700 gal) aluminum tank which was used in past space program testing. A standpipe was installed in the tank to localize collector return water so that it could be more efficiently supplied to the heating/cooling loop. This was done to preclude the need for expensive remote operating tank bypass valving often

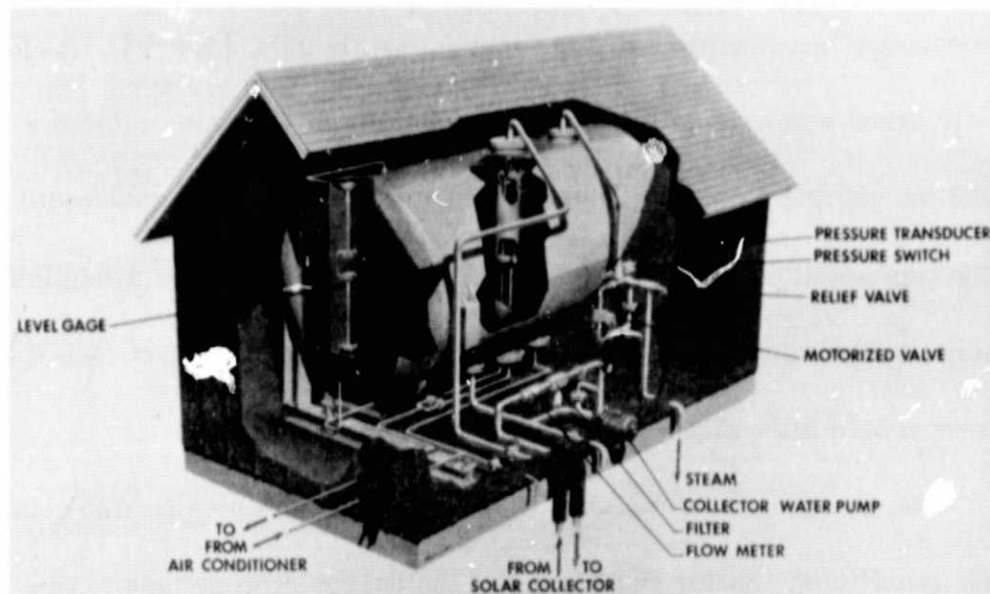


Fig. 5. Thermal storage hot water tank.

used to divert flow from the collector directly to the heating/cooling loop. The tank was filled with only 16.4 m^3 (3600 gal) of water to allow for adequate gas volume. Since easy access was desirable, a wooden structure was built around the tank. Attic-type fiber glass insulation was blown into the volume between tank and structure to inhibit heat loss.

Air Conditioner/Heating Loop. Cooling is accomplished by using an ARKLA hot water driven, 3-ton aqueous LiBr absorption air conditioner. A cooling tower is used in conjunction with this unit to reject heat in the condenser and absorber sections. In the event hot water temperatures in the energy storage tank drop below the value required to sustain operation of the air conditioner, an auxiliary water heater automatically activates to maintain the required air conditioner inlet temperature. In the heating mode, hot water is diverted from the

air conditioner to a simple liquid/air tube and fin heat exchanger. The hot water is then used to warm the house air directly. If the water is too cool to warm the air sufficiently, water flow is stopped and duct mounted strip heaters are activated to supply heat to the house. In both modes a single fan forces air over heating and cooling coils. A simplified diagram depicting the control logic is given in Fig. 6.

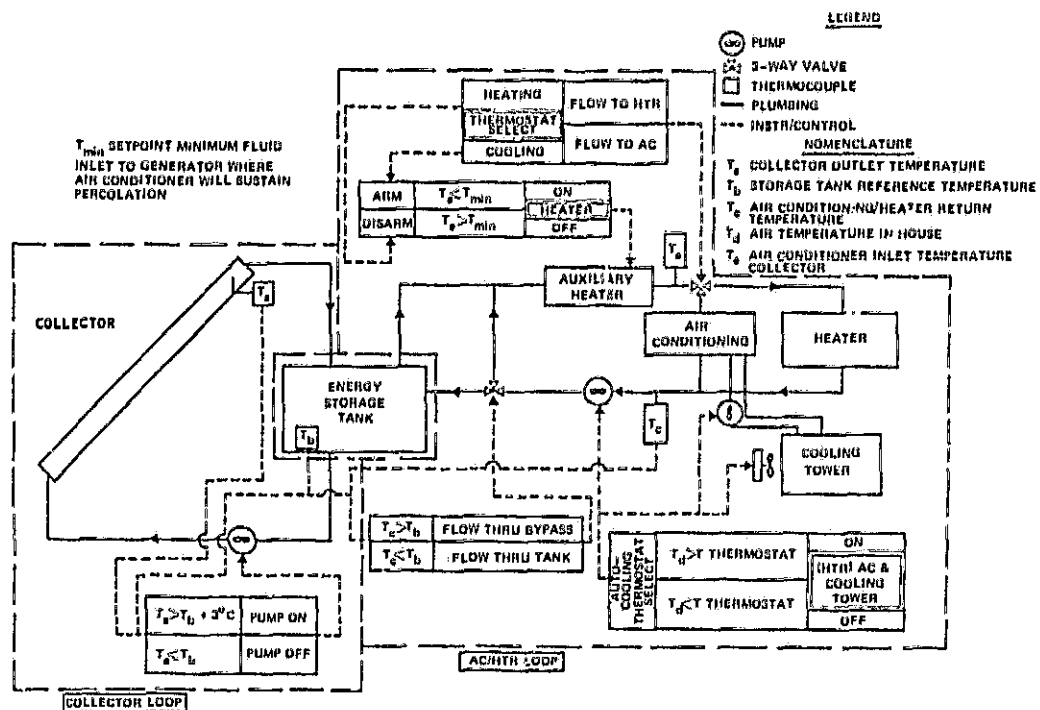


Fig. 6. Simplified control logic.

3. SYSTEM OPERATION

Problems have been encountered during the first year of operation, and in several cases modifications have been made to improve performance. Brief summaries of some of the significant problems and modifications are provided in the following sections.

Air Conditioner Control System Modification. The initial air conditioner/ system control logic design was based upon the qualification test data furnished with the unit and a plot of generator inlet temperature versus cooling tower temperature furnished by the manufacturer. The unit was initially operated at or near the rated conditions [i.e. at inlet water temperatures to the generator $\approx 93^{\circ}\text{C}$ (205°F)]. Bypass flow around the generator was originally incorporated to avoid over temperature conditions within the unit.

The primary problem encountered with the system described was that energy usage by the air conditioner was excessive. Data accumulated during system operations indicated that at water inlet temperatures to the generator between 92°C and 96°C (198°F and 205°F), the energy input to the generator ranged between $15,860\text{ J/s}$ ($54,000\text{ Btu/hr}$) and $19,600\text{ J/s}$ ($67,000\text{ Btu/hr}$). At water inlet temperatures between 98°C and 109°C (208°F and 228°F), the energy input varied between $21,100\text{ J/s}$ and $24,300\text{ J/s}$ ($72,000\text{ Btu/hr}$ and $83,000\text{ Btu/hr}$). These data were taken at the manufacturer's recommended flowrate of $0.00063\text{ m}^3/\text{s}$ (10 gpm) of water through the generator, and at water temperatures supplied from the cooling tower ranging from 24°C to 27°C (76°F to 82°F).

Studies were initiated to investigate alternate control schemes which might lower the generator energy requirement. Because insufficient data were available on the air conditioner unit to allow any degree of confidence in making

decisions on a revised control scheme, a decision was made to terminate full system testing and to begin a test program on air conditioner performance. The objective of the test was to establish coefficient of performance (COP), energy input requirement to the generator (\dot{Q}_{gen}), and cooling capability of the air conditioner (\dot{Q}_{AC}) with variable generator inlet water temperatures and variable water flowrates. Test data indicated that the air conditioner COP would increase at lower generator inlet temperatures. It also proved that the COP is a function of generator water flowrate. The key to operating at lower water inlet temperatures and lower flowrates was to sustain percolation at the conditions selected.

Test data were used to modify the system control logic resulting in considerable energy savings due to lower energy inputs to the air conditioner generator. Representative test data are provided here to demonstrate the results of the tests, more detailed data are given in Reference 1. Since these tests were run using the house as the test bed a number of important test parameters, such as house air temperature and cooling tower water supply temperature, could not be adequately controlled thereby introducing appreciable data scatter. Figure 7 depicts expected generator energy input requirements versus water inlet temperature for water flowrates of 0.00063, 0.00031, 0.00019, and 0.00014 m³/s (10, 5, 3, and 2.3 gpm). These data were derived from the air conditioner performance tests. The vertical lines in Fig. 7 represent the temperature control points at which bypass flowrate around the generator is

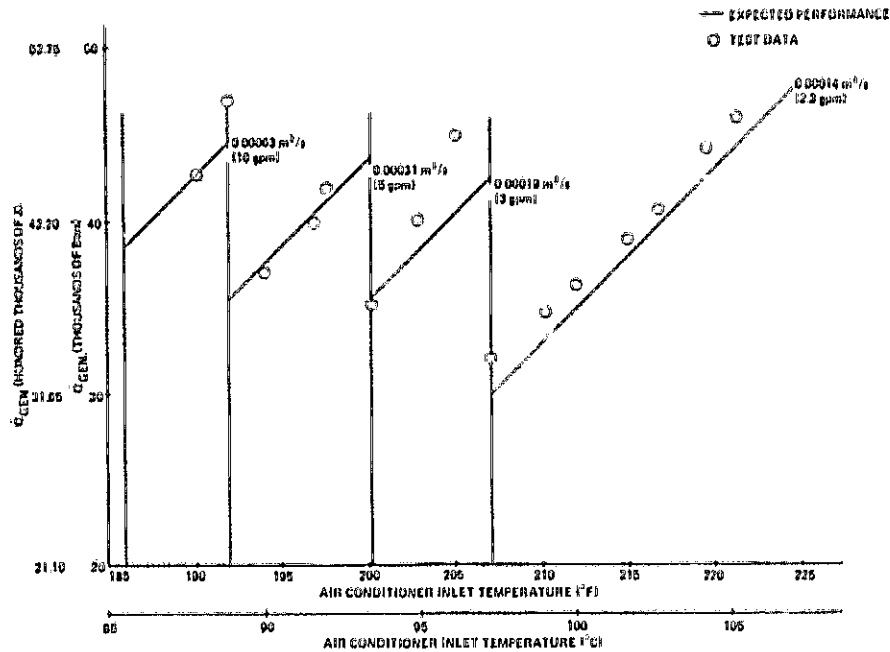


Fig. 7. Modified control system performance.

changed in the revised control logic. Figure 7 also provides system performance test data which have been accumulated since system operation was reinitiated, and these data provide an indication that the expected performance is being achieved. Figure 8 depicts the improvement in COP realized by controlling the flowrate through the generator as indicated.

Using these data the control system was modified within the envelope of existing hardware. The modified control logic has the following three basic features (Fig. 9):

- a. The energy input to the generator is minimized by bypassing a portion of the flow around the generator at water temperatures greater than those required to maintain percolation. At water supply temperatures below

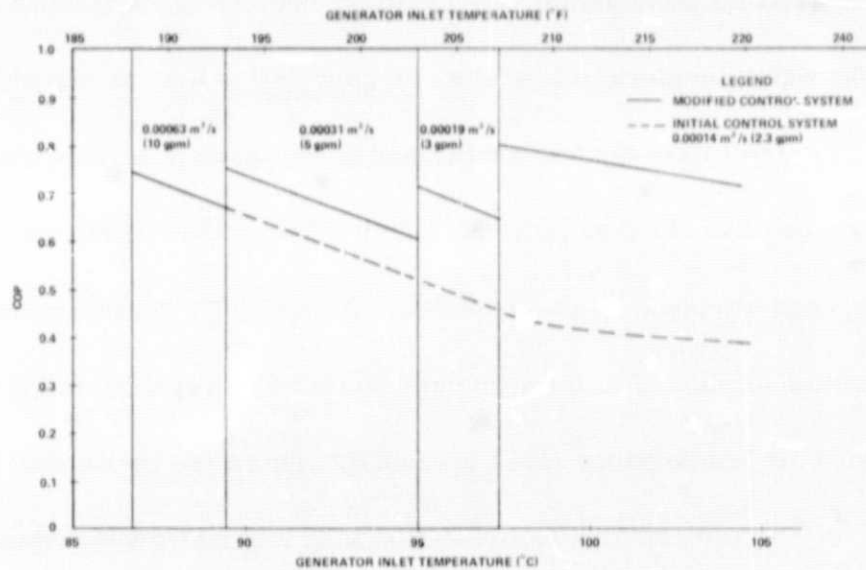


Fig. 8. Effect of generator inlet temperature and flowrate on air conditioner COP.

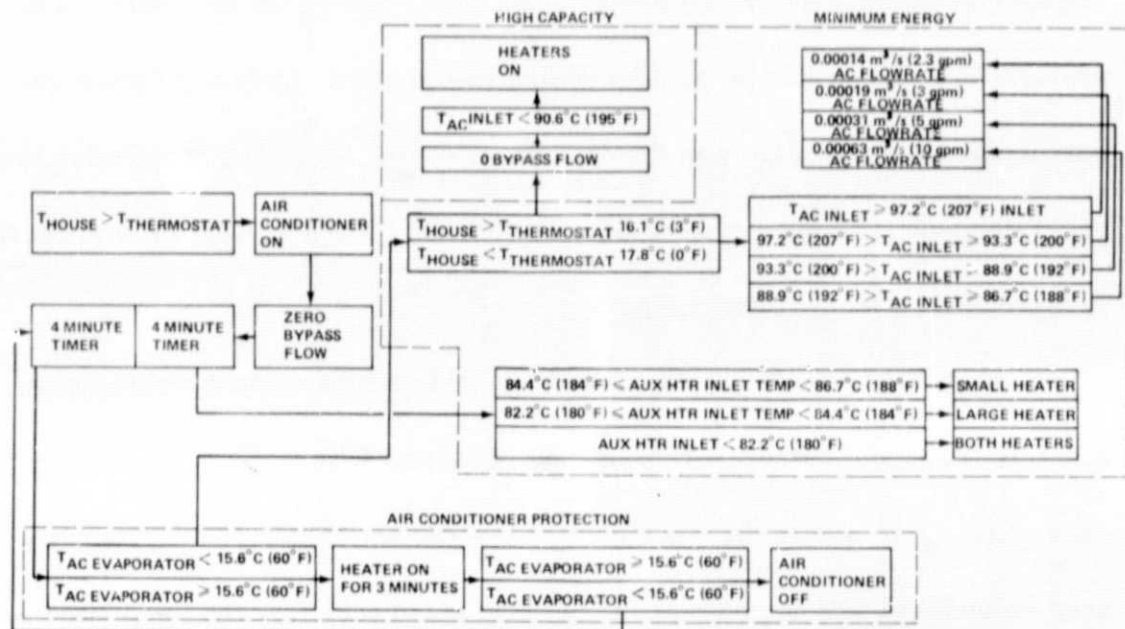


Fig. 9. New air conditioner logic system.

that required for percolation, the auxiliary heaters are activated in stages to keep the water temperature as close to percolation loss as possible.

b. Operating the air conditioner in the mode described reduces its cooling capacity. During periods of high thermal load within the building, the cooling capacity could be unacceptable. As a result, a high cooling capacity loop was incorporated to force the unit to its rated capacity in the event that the house air temperature rises excessively above the thermostat set point.

c. An air conditioner protection loop was added which deactivates the unit if percolation loss occurs.

As a result of incorporating the modified control scheme, the energy required to operate the air conditioner has been reduced considerably. The average COP for the initial system design was approximately 0.42 while the post modification average was approximately 0.70. Lowering of the minimum generator supply temperature from 96°C to 86°C (205°F to 188°F) also resulted in increased collector efficiencies.

It should be noted that the advantage of this type control technique is strongly dependent on the system design. Systems with large daily temperature excursions (i.e. small storage tanks, oversized collectors, or high performance collectors) are helped more than those sized such that the temperature is normally near the minimum air conditioner operating temperature. The primary disadvantage of such a system is higher initial cost, added valving

and control, and lower reliability. However, if the design is executed properly these disadvantages can be minimized. Although in the interest of time the new flow control system used two existing bypass valves, other schemes such as continuous throttling, variable bypass, or temperature mixing valves may improve this control technique and possibly reduce costs.

While discussing the operation of the air conditioner, it is interesting to note the variations of the operating envelope for different geographical locales. The varied environments in which a given unit operates can significantly alter the unit's minimum operating temperature and cooling performance. These effects are primarily induced through the cooling tower performance. For example, for a humid region the average wet bulb temperature may be quite high causing temperatures delivered to the condenser to be correspondingly high. Using analytically generated performance data (Fig. 10) the percolation loss temperature, indicated by an abrupt decline in COP on the left of each curve, increases dramatically as the condenser temperature rises. This is also due to changing the aqueous LiBr concentration ratio. A line can be constructed on Fig. 10 which approximates the optimum LiBr temperature versus COP for a range of condenser temperatures. Taking into account the cooling water temperature rise in the absorber together with appropriate corrections for cooling tower inefficiencies, the ASHRAE 97.5 percent design wet bulb temperatures can be used to determine the minimum LiBr operating temperature for a number of cities through the US. Using test data from the

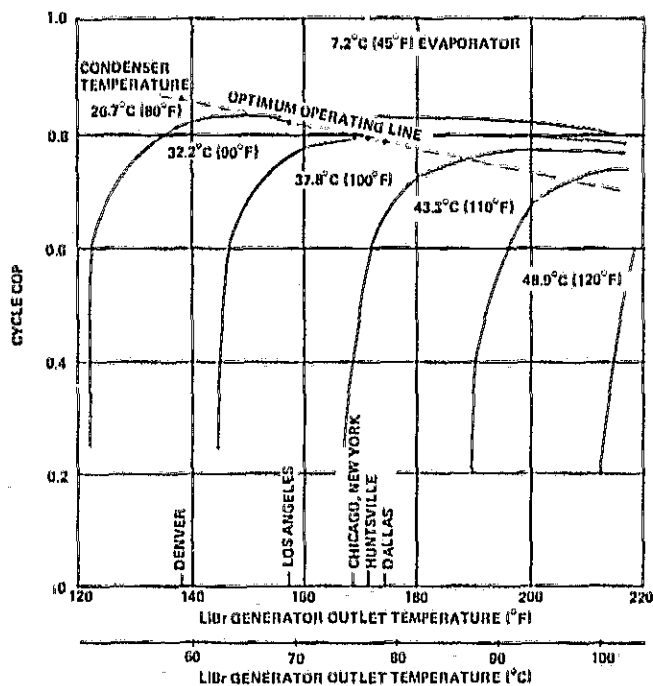


Fig. 10. LiBr/ H₂O absorption cycle performance.

present ARKLA unit, the generator hot water inlet temperature required for each city can be approximated by simply adding 14° C (25 °F) to the LiBr outlet temperature in this figure. It can be seen that variations of 17° C (30° F) in the minimum operating temperature are possible for the cities considered. As indicated, the arid regions yield better performance than the humid regions. Figure 10 also indicates higher COPs which result from lower operating temperatures. This discussion is designed to show that the performance values quoted for the MSFC solar house are applicable only to a similar humidity region.

Low Cost/ High Reliability Solid State Control System. Even without the special control system required for the absorption unit, the logic control system required for a solar system is inherently more complex than that of present

day conventional systems. For this reason, as well as reliability problems experienced with a conventional electromechanical system initially installed in the MSFC solar house, a solid state control system was designed and installed in the house. This system was designed to be compact and to have low cost. It uses commercial grade components, making use of such recent developments as integrated circuit chip multiplexers and new high quality amplifier configurations now in mass production. The expected size envelope for a completely developed unit would be only slightly larger than a conventional thermostat. Figure 11 shows a breadboard of the new collector control logic.

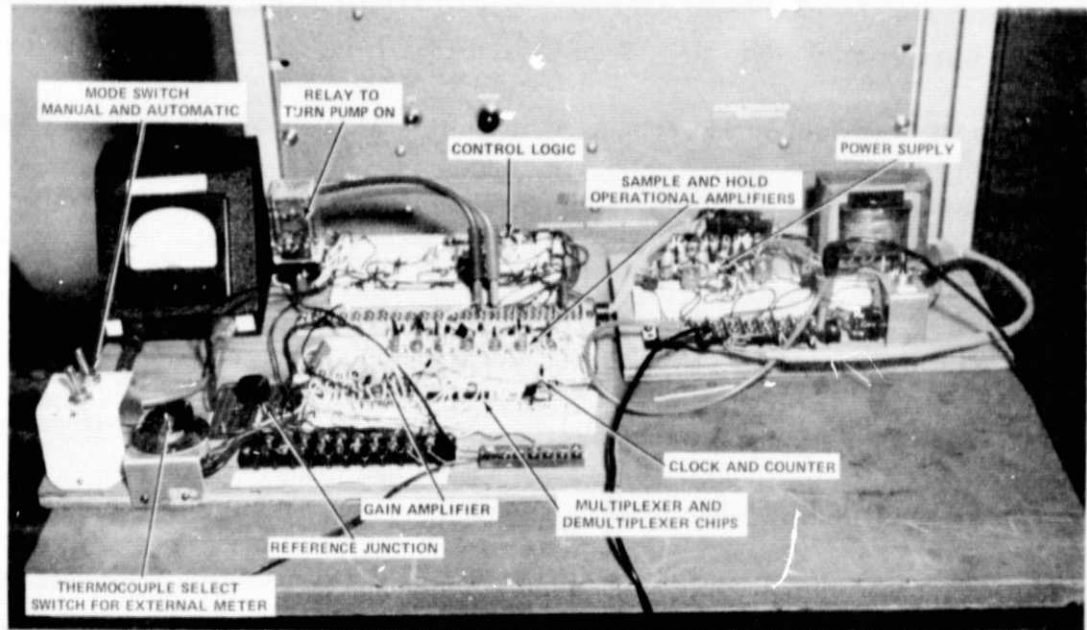


Fig. 11. Collector loop solid state control system breadboard.

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Second Generation Collector. Of the 31 collector segments, 27 were initially covered with 0.05 mm (0.002 in.) thick Tedlar and the remaining four with 0.10 mm (0.004 in.) Tedlar. The entire system was mounted on the roof in late April 1974. Tears in the 0.05 mm (0.002 in.) covers were first noticed in early September 1974. After that time, numerous tears appeared in the 0.05 mm (0.002 in.) covers. After the 0.10 mm (0.004 in.) covers had been exposed approximately 12 months, they also began to tear.

Cover tears occurred most frequently after high wind and rain. Most tears were on a horizontal line and the majority of tears emanated from or crossed over the 0.05 m by 0.10 m (2 in. by 4 in.) wire mesh support. Most tears were from 0.05 m to 0.20 m (2 to 8 in.) long, although a number extended across the entire 0.6 m (2 ft) segment width. Tears were immediately repaired by either using clear Teflon tape or, in the case of larger tears, by using Tedlar patches.

The exact cause of the tears is unknown. However, from observations it is reasonable to assume they were caused by a combination of effects with primary contributors being improper support of the Tedlar, fatigue, and wind flutter. The common fence wire used to support the Tedlar was bonded to the cover. This bond detached in numerous places allowing an abrasive action to take place between the wire and cover. In some areas this action was increased by light rust on the wire. This was not the sole cause for tearing, however,

since a number of tears occurred away from wire supports. It was also noted that some failures exhibited signs of embrittlement around the tear zone.

As a result of the cover tears, an immediate collector modification was deemed necessary. Since development work by MSFC on new low cost collector configurations had not progressed far enough to allow replacement with a complete new design, an interim fix was applied. At the time this fix was instigated, the 0.10 mm (0.004 in.) cover had survived over 9 months with no failures. Consequently, the new generation collectors used 0.10 mm (0.004 in.) Tedlar. A new Tedlar support scheme was included in the new generation design in an effort to improve cover life. This new scheme uses only horizontal wire spaced at 0.3 m (12 in.). The rust prone galvanized wire was replaced with aluminum wire. Based on recommendations from the Tedlar supplier, two of the segments are covered with 0.10 mm (0.004 in.) tightly stretched Tedlar unsupported by wire. This support technique will be compared to the widely spaced wire support scheme in future testing. Plans are also being made to test glass covered schemes.

An improvement in humidity control was incorporated together with the support change. The concept was developed on a prototype test bed. The scheme (Fig. 12) uses a passive desiccant bed filled with silica gel. The bed is covered with a black nickel coated plate and is isolated thermally from the collector panels. It works by "breathing in" at night and "breathing out" during

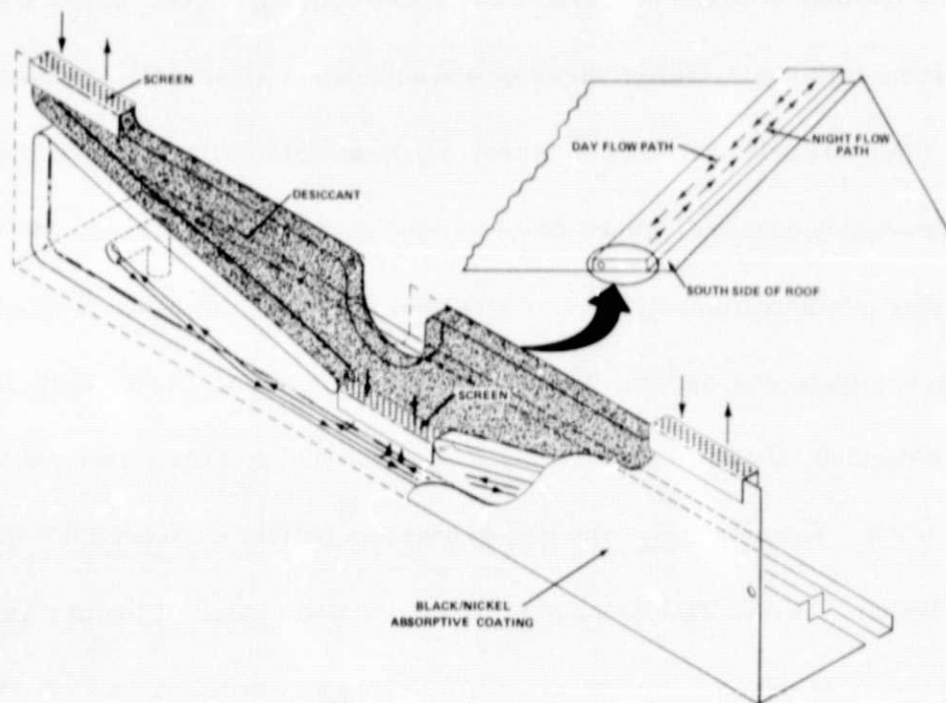


Fig. 12. Passive desiccant bed schematic.

the day, eliminating the need for active blowers. A vent provided on the lower end of each collector segment, which is connected to the bed, allows the cooling segment to draw moist air in at night. As it flows through the bed, water from the moist outside air is absorbed by the desiccant. During the day as the collector warms, air is expelled through the same vent providing a transport medium for desorbing the bed. The desorption of the silica gel is attained by the heated bed which results from being in intimate thermal contact with the black nickel coated cover plate. Tests indicate that the performance of this device is superior to the active concept used initially.

Installation of the new segments was accomplished in increments of four, starting in January 1975. The final new generation segments were installed in May 1975. No problems have been encountered with the new collectors. Figure 13 shows the old and new generation collectors side by side for comparison.

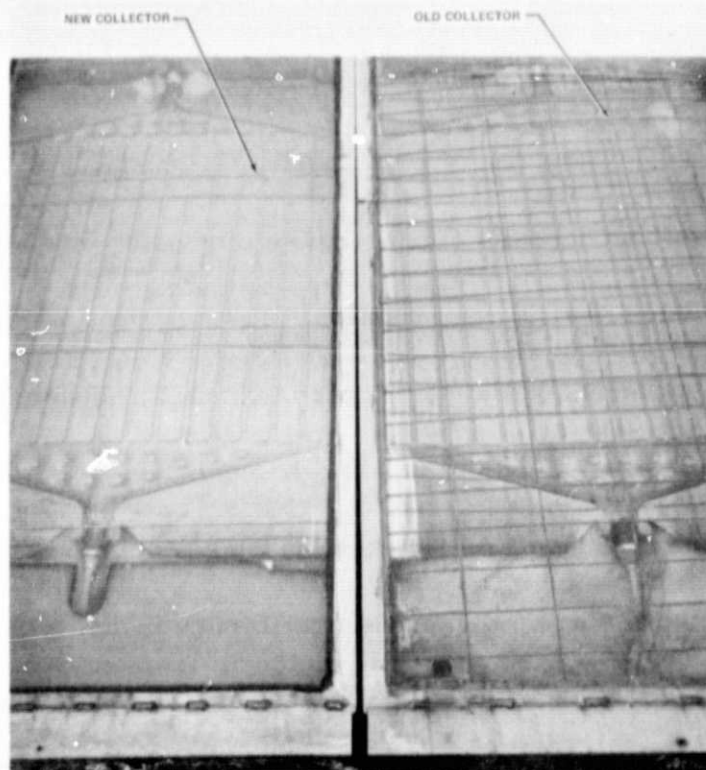


Fig. 13. Old and new generation collector configuration.

During the initial 8 to 12 weeks of system operation, noticeable discoloration or "clouding" of the Tedlar occurred. Figure 14 shows a sample of Tedlar which was exposed for 6 months in a prototype test. For comparison, a clear unused sample is also shown. The degradation was found, by chemical analysis,

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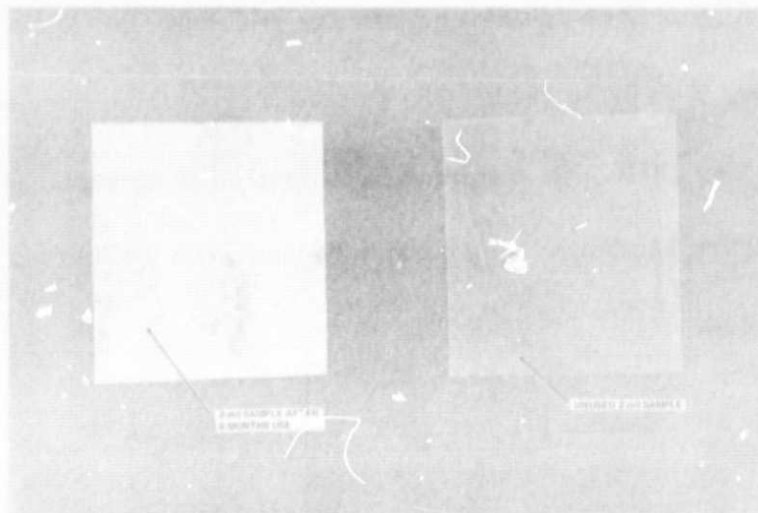


Fig. 14. Tedlar offgassing sample.

to have resulted from deposits of condensible offgassing products from a binder used in the backside fiber glass insulation. Tests of two samples taken from representative segments on the solar house indicated transmittance values of 82.6 and 73.4 percent. These values may be compared to initial undegraded transmittance measurements of 94 percent. This problem can be avoided in the future by either using preoffgassed insulation or by using fiber glass qualified for higher temperature use. New covers have shown no signs of contamination. This is thought to be due to previous inservice offgassing of the insulation.

Black Nickel Coating Property Degradation. Although a dehumidification system was incorporated into the initial collector design to preclude black nickel coating degradation, comparison of pretest and post-test coating properties indicates that significant degradation occurred. Using an average of

over 1000 readings, the average solar absorptance was found to have decreased by 14 percent over a 12 month period. No appreciable change in the infrared emissivity was detected.

Since the coating was exposed to rain water, due to the failure of the Tedlar covers, it is not possible to determine the level of degradation that would have occurred without a cover failure. It should be noted that studies are currently underway at MSFC to examine techniques of improving the black nickel coating stability in the presence of moisture. Additional studies are examining other selective coatings to determine their feasibility for use with solar collectors.

Internal Flow Distribution Manifold for Energy Storage Tank. During early testing it was noted that in certain flow configurations the fluid temperatures being delivered to the air conditioner were considerably below the bulk temperature of the energy storage tank. This discrepancy was most apparent in the configuration with the air conditioner operating without collection. Examination of temperature profiles in the tank indicated that channeling within the tank was causing "short circuiting" of flow from the cold air conditioner return to the air conditioner supply (Fig. 15). This was surprising in that the air conditioner return line was directed away from the supply line and the supply line was shrouded by the tank standpipe, which contains only small holes through which flow can enter. To eliminate this undesirable phenomenon, a

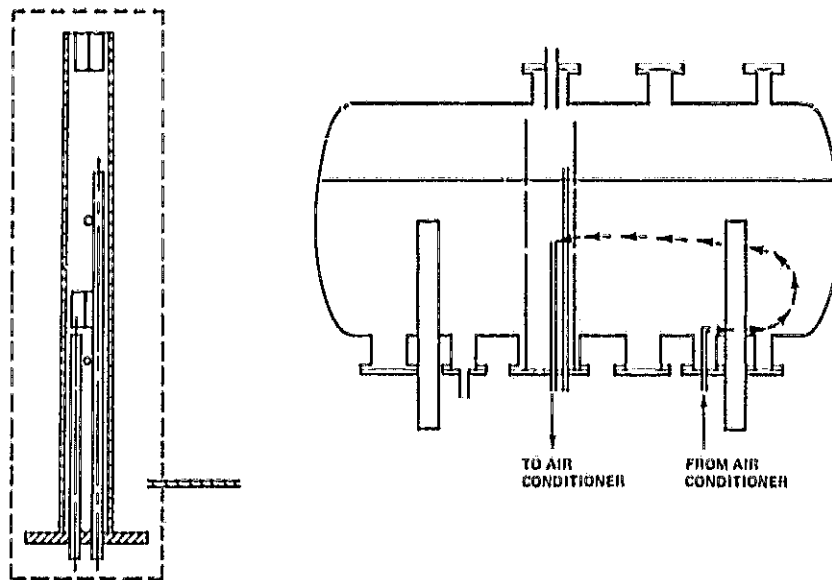


Fig. 15. Tank flow schematic.

fluid manifold was installed in the air conditioner return line (Fig. 16), see Reference 3. This manifold distributes the cold fluid returning from the air

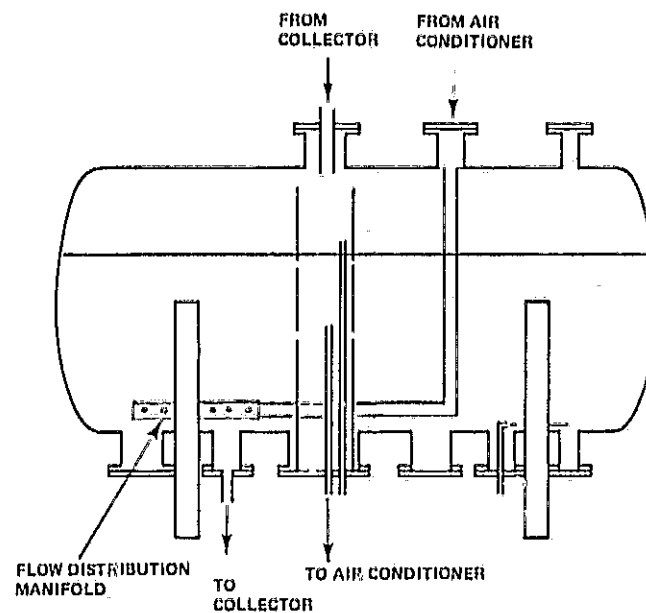


Fig. 16. Energy storage tank manifold.

conditioner over the bottom of the tank near the collector supply exit. Data indicate that this scheme inhibits the short circuiting while further exaggerating the temperature stratification phenomena. With this configuration the stratification phenomena allow colder water to be supplied to the collector than is supplied the air conditioner/heater loops.

4. PERFORMANCE SUMMARY

Collection. The collector efficiency of interest from a system viewpoint is the total integrated or gross collector efficiency given by

$$\eta_T = \frac{\int_{\text{day}} \dot{Q}_{\text{collected}} dt}{\int_{\text{collection period}} \dot{Q}_{\text{incident}} dt}$$

where $\dot{Q}_{\text{collected}}$ is the rate of energy collection and $\dot{Q}_{\text{incident}}$ is the rate of energy incident of the 120.9 m² (1300 ft²) collector. For comparison with specific collector performance, the instantaneous collection efficiency is of greater interest:

$$\eta = \frac{\dot{m} c_p (T_{\text{col in}} - T_{\text{col out}})}{\dot{Q}_{\text{incident}}}$$

where \dot{m} is the mass flowrate of water through the collector, c_p is the specific heat of the water, $T_{\text{col in}}$ is the collector inlet temperature, and $T_{\text{col out}}$ is the

collector outlet temperature. Figures 17 and 18 give bar charts of these two parameters for the entire year. The instantaneous efficiency, η , is given at the peak flux period, near solar noon. Values of solar flux and fluid inlet

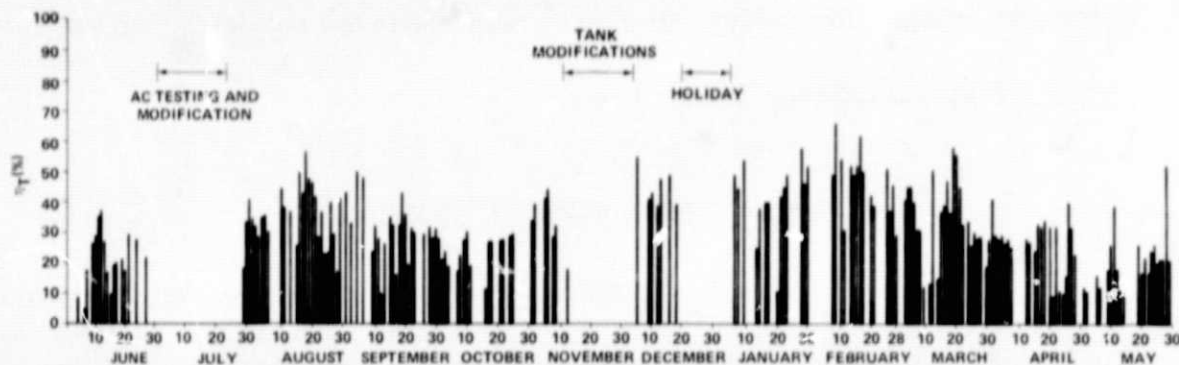


Fig. 17. η_T versus day of year.

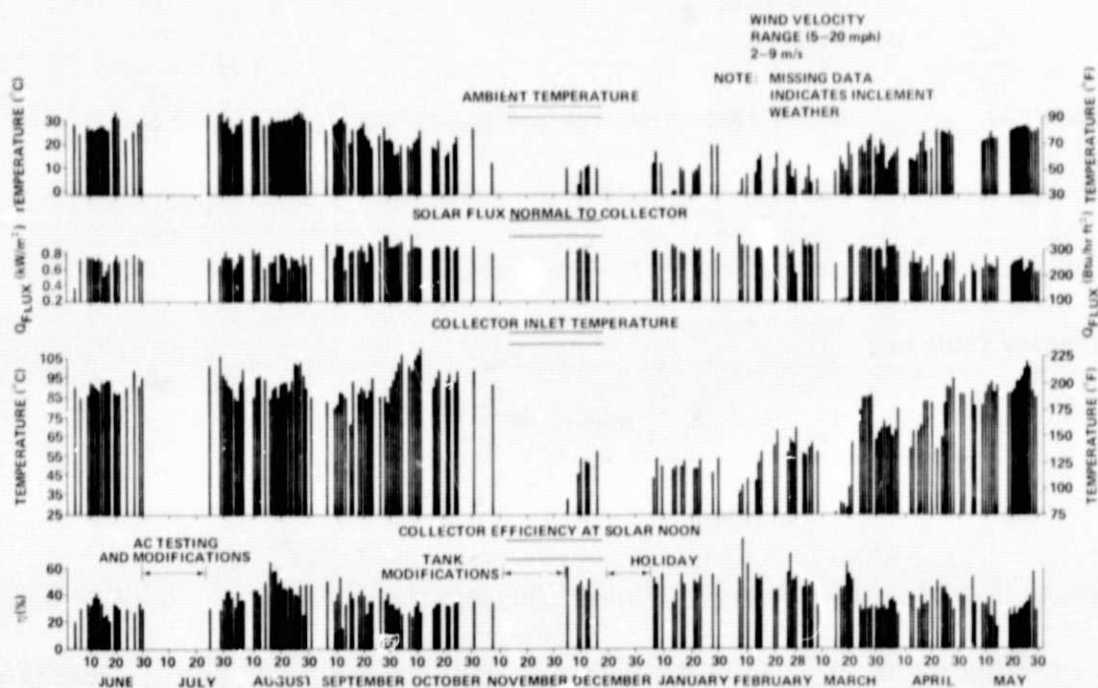


Fig. 18. η versus time of year with solar flux and inlet fluid temperature.

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temperature are also given. Although the collector has had several problems, as reported earlier, its performance was quite good. The instantaneous efficiency near solar noon averaged 36 percent for the cooling season. Due to colder water temperatures supplied the collector, the winter efficiency averaged 43 percent and the resulting yearly average was 40 percent. The average integrated efficiencies for similar periods were 31 percent, 40 percent, and 35 percent, respectively.

Overall System Performance. Although no one parameter is an indicator of solar system performance, one of the most widely used references is that of percent solar (% S) given by

$$\text{Summer: \% S} = \frac{\dot{Q}_{\text{gen}} - \dot{Q}_{\text{aux htr}}}{\dot{Q}_{\text{gen}}}$$

$$\text{Winter: \% S} = \frac{\dot{Q}_{\text{Hx}}}{\dot{Q}_{\text{heating}}}$$

where

\dot{Q}_{gen} = thermal energy input to air conditioner

$\dot{Q}_{\text{aux htr}}$ = the auxiliary heater energy input to the fluid stream

\dot{Q}_{Hx} = energy input to the winter liquid/air heat exchanger

\dot{Q}_{heating} = the total heat energy supplied to house

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Other factors of importance in evaluating the total effectiveness of a solar system are initial system cost and power consumption. Unfortunately, the initial cost of a nonproduction facility of this type is not meaningful. Power consumption is very sensitive to fluid flow resistance which is not optimized. Matching of the fluid system to the pump or fan for maximum efficiency was not attempted because of the desire to maintain flexibility in the basic system. For this reason only percent solar values are reported (Fig. 19). These values must also be used carefully because they are functions not only of the solar system performance but also the thermal load imposed on the house, external environmental effects, and the insulation characteristics of the structure. Test data revealed that the summer, winter, and yearly average percent solar values were 43, 100, and 57 percent, respectively.

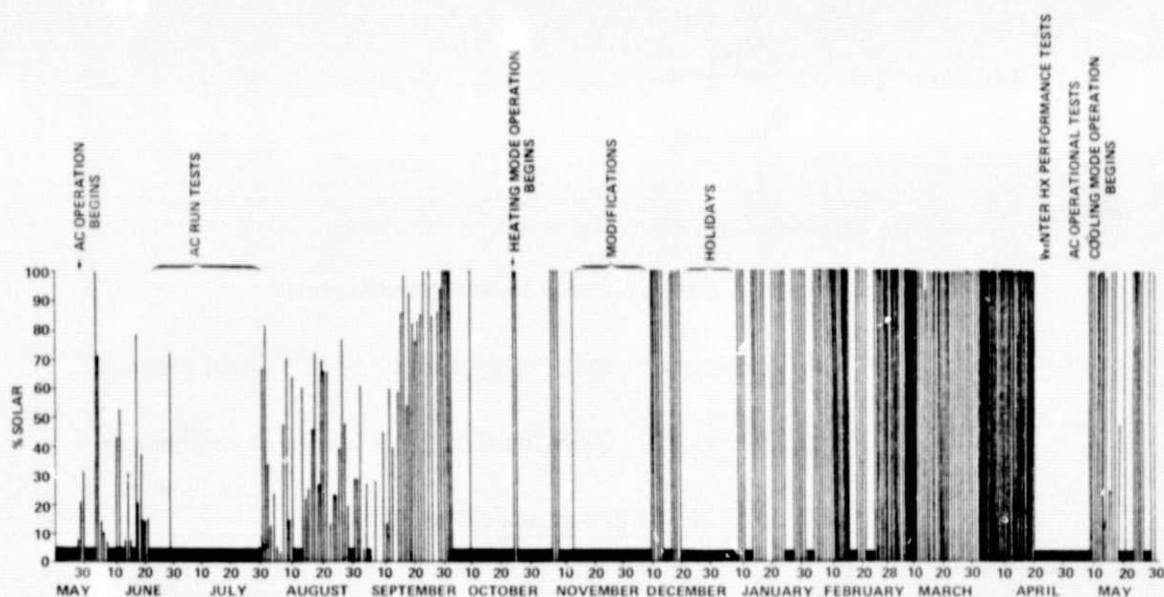


Fig. 19. Percent solar variation with day of year.

5. CONCLUSIONS

To date the MSFC solar house operation has fulfilled the intended goal of providing a technical experience, which has been summarized here. Some of these conclusions which can be made from the operations discussion presented earlier in this paper are as follows:

a. Operation of the MSFC solar house has provided valuable information concerning the importance of subsystem interactions on overall system performance. As an example, subsystem tests were run on the absorption air conditioner to determine its optimum operating conditions. These tests proved that the air conditioner could operate at lower generator energy input levels and temperatures than were specified by the manufacturer. The control system was modified to allow operation at these improved conditions. As a consequence of this change, the air conditioner not only operated more efficiently but the performance of the solar collector also improved because it was allowed to operate at a lower temperature.

b. During a typical summer, the solar system in its current configuration can supply 50 percent of the thermal energy required to operate the air conditioner. In the winter mode the solar system provides nearly 100 percent of the heating required.

c. Tedlar collector cover support schemes are of paramount importance in achieving long life. Schemes with minimum support are expected to yield longer life.

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d. Using current black nickel coating techniques, significant degradation occurred in the solar absorption properties when the coating is exposed to high humidities and direct water impingement. Further work is being pursued at MSFC in improving the coating's resistance to moisture.

e. Care must be taken to avoid fluid "short circuiting" in the energy storage tank. A technique which has proven successful is to utilize a multi-orificed manifold to distribute flow within the tank.

f. Use of low cost solid state control equipment has proven to be feasible. Use of these components will allow packaging of complicated solar system electronic logic within a compact installation.

Other observations which are more general in nature and are not supported in the text are:

a. An obvious, although little discussed, point is the importance of the technique used to supply auxiliary energy. From a minimum resources viewpoint, the technique most desirable is the one that uses the least energy or is the most efficient. This is normally a technique that utilizes the least number of intermediate conversion steps. An example of this is illustrated by comparing an electrically fired heater to a gas fired heater. The thermal losses associated with converting a natural resource (e.g., coal, oil, gas, etc.) in a steam plant into electrical energy, transmission, and subsequent reconversion via a heating element back into thermal energy results in low

efficiency; whereas, in a gas system located at the use site the only significant inefficiencies are those associated with flue losses and heat leakage. From this, it is obvious that the most economical form of resource is to provide auxiliary heat via gas or fuel oil heaters.

b. The current absorption air conditioners require significant electrical energy support. This is primarily the result of the cooling tower which is required to eject heat from the condenser section. This device uses a fluid pump to transfer energy from the tower to the condenser as well as a fan in the tower to stimulate evaporation. The additional power consumption imposed by this device added to the relatively inefficient addition of auxiliary energy (when compared to a vapor compression cooling device) demands that higher percentages of solar energy be provided in the cooling mode than is necessary in the heating mode to conserve energy resources.

c. Installation of a solar energy system such as the one at MSFC requires a significant amount of onsite effort because all subsystem components are delivered to the site and are mated to form the system. This method of operation is very costly in materials and labor and is a significant part of the system cost. These costs could be significantly reduced by "packaging" major subsystems such as the air conditioner, storage system, and controls. This would allow the major site effort to be installation of the solar collector and plumbing interfaces. In addition to reducing site labor and material cost, the

packaging concept allows essentially a system level acceptance test to be performed at the manufacturer's plant. Therefore, reliability is increased and maintenance costs will be reduced. Based on this, the systems approach offers great opportunity for overall system cost reduction.

REFERENCES

1. W. R. Humphries and D. E. Melton, "Solar Residential Heating and Cooling System Development Test Program — Initial Report." NASA TM X-64924, September 1974.
2. W. R. Humphries, "Status of the Marshall Space Flight Center Solar House." Proceedings of Southeastern Solar Energy Conference, University of Alabama in Huntsville, March 1975.
3. W. R. Humphries, E. I. Grigg, and H. C. Hewitt, "Fluid Manifold Design for a Solar Energy Storage Tank." NASA TM X-64940, June 1975.

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APPROVAL

DESIGN AND OPERATION OF A SOLAR HEATING AND COOLING SYSTEM FOR A RESIDENTIAL SIZE BUILDING

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



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